

SAGE AND 3M CORPORATION

Smart-Window Technology

Each day millions of Americans spend the day inside buildings with windows as their only connection to the outside world. Windows allow the sun's warmth and light to permeate our living space and offer views of the outside. Unfortunately this luxury brings with it the high costs of heating, cooling, and shading. Windows, which have largely escaped technological advances, are now being taken into the high-tech arena.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

A Strong Potential Seen for Thin-Film Electrochromics

For years, thin-film electrochromics has been seen as a possible way to make "smart windows"—windows with an electrochromic (EC) coating that can electronically control the flow of solar light and heat in response to changing outdoor conditions. On hot, sunny days the tint in the windows would darken to reduce glare and block out heat. On cold, cloudy days the windows would clear to allow sunlight and heat to fill the office or home. In addition to reducing energy requirements, the electric shading of smart windows may eliminate or reduce the need for expensive blinds or curtains.

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The race for a profitable and reliable electrochromic production process has been pursued aggressively for more than 15 years. Electrochromic technology is appealing as a potentially broad-based area that promises to be useful not only in windows in buildings, but also for adhesive tape films for automotive windows, electrically adjustable eyewear, advanced flat batteries, and other applications. The potential for multiple applications and broad benefits of thin film electrochromics has made it one of the most intensely researched areas of material science around the world.

U.S. Partnership Develops to Pursue the Technology

Against this backdrop of worldwide competition, enters



The top photo shows two electrochromic smart windows in the clear state allowing in more daylight and minimizing the need for interior lighting. In the lower photo, a window darkens to eliminate glare and improve comfort and energy management while maintaining vision through the glass.

John Van Dine, who in 1990 founded a small company in Piscataway, New Jersey, called Sun Active Glass Electrochromics, Inc. (SAGE), to develop glass coatings. Following an unsuccessful ATP proposal in 1991, he was encouraged to strengthen his plan by finding a technology partner. To that end, in 1992, SAGE formed a joint research and development partnership with the 3M Corporation, and the two companies brought in scientists from Rutgers University's Center for Ceramic Research as additional collaborators. The joint venture submitted a proposal in ATP's 1992 General Competition and was successful.

The ATP provided \$3.472 million, matched by \$3.821 million from the 3M Corporation and SAGE, for a project to develop advanced electrochromic materials and production processes. The project was designed to

PROJECT HIGHLIGHTS

production processes leading to devices suitable for electronically controlled smart windows and other applications.

Duration: 6/07/93 – 12/31/96

ATP Number: 92-01-0123

Funding (in thousands):

ATP	\$3,472	48%
Company	3,821	52%
Total	\$7,293	

Accomplishments:

This project led to major advances in electrochromic materials and processes and opened up potential applications in a variety of useful products. The project:

- developed new understanding of large-area electronic devices;
- produced several working prototypes of smart windows for competitive performance testing at the National Renewable Energy Laboratory (NREL) that were rated best overall;
- produced prototypes that tests show are capable of tens of thousands of tint changes (cycling), equivalent to more than 15 years of use, without degrading performance;
- produced prototypes that are estimated to reduce the transmittance of light and heat, depending on the setting, by 30–96 percent, and to yield up to a 50 percent reduction in energy costs for commercial buildings, as demonstrated by Berkley National Laboratory and ASHRAE tests;
- produced two patents for technologies developed in the project:

“Counterelectrode Layer”
(No. 5,919,571: filed 7/14/1997, granted 7/6/1999);
“Sputtering of Lithium”
(No. 6,039,850: filed 5/29/1997, granted 3/21/2000).

Commercialization Status:

Sage announced on June 17, 1998, that it had reached an agreement with Apogee Enterprises, Inc., to develop, produce, and market smart windows. This commercialization venture is a direct result of the encouraging test results for the prototype windows developed in the project. A leading fabricator, distributor, and installer of value-added glass

products, Apogee, and its subsidiary, Viracon, will target the high performance architectural glass market. In addition, SAGE has recently received a DOE-NETL grant that will help it to focus further on issues affecting efficiency of fabrication.

Sage has successfully set up pilot line operations, including an industrial scale coater and fabrication systems, leading to the production of full size switchable windows measuring up to five square feet in area.

In addition, Sage has entered into a number of industry alliances to develop and commercialize smart window products. In February 2001, Sage and Honeywell, the global home and building controls leader, announced an alliance whereby Honeywell will develop and manufacture the systems for Sage's smart windows, enabling user control of EC glazings to transform windows into comfort-enhancing and energy-saving appliances. Sage and Velux, a leading global producer of skylights and roof windows, have partnered to test market Sage skylight products. Sage also has joint projects with other original equipment manufacturers — i.e., Pella and Four Seasons Solar Products Corporation — for product development, joint testing, and market introduction. Sage expects to move into volume manufacturing by the end of 2002, when it will significantly increase its staffing level.

Outlook:

Industry experts have predicted that electrochromic windows are three-to-five years from wide-scale commercial use. New manufacturing techniques must be developed that will eliminate even the smallest defects in the electrochromic layers. These defects are the major barrier to producing economical, large-size architectural windows. Other potential applications of electrochromic technologies include next-generation flat, compact batteries; new and retrofitted automobile windows; and adjustable eyewear. The outlook appears excellent for this technology.

Composite Performance Score: * * *

Number of employees: 5 at project start; 10 at project end

Company:
SAGE Electrochromics, Inc.
2150 Airport Drive
Faribault, Minnesota 55021

Contact: Neil Sbar

Phone: (507) 333-0078

...the two companies brought in scientists from Rutgers University's Center for Ceramic Research as additional collaborators.

build upon the EC synthesis and processing experience of tiny SAGE, while also drawing upon the module

technology and manufacturing and commercialization skills of the Fortune 500 company, 3M. SAGE was to focus on the technical requirements relating to EC glass, and 3M on the technical requirements relating to tape.

What Makes Smart windows Smart?

The electrochromic (EC) window consists of a series of thin conducting layers that change optical properties when an electrical voltage is applied. Each layer is

thinner than a sheet of paper, and together the layers support the transport of electrons and ions. One layer of the film—colorless lithium metal-oxide—acts as the positive electrode, another layer—tungsten oxide—acts as the negative electrode. When voltage is applied, lithium ions begin to traverse from the positive electrode to the negative electrode, a process that turns the tungsten oxide to lithium tungstate (a light absorbing, blue-gray substance), formed by the chemical addition of ions. The longer the voltage is applied, the more ions are transferred, and the darker the window becomes. During the production process, ceramic thin-film layers containing the electrodes are deposited with great precision onto a transparent substrate primarily by a vacuum coating technique. The multilayered electrochromic device is then mounted inside a conventional glass frame. The conducting layers are connected to a power supply, controlled by a switch. The switch allows the number of ions, and thus the amount of light transmitted in the electrochromic film, to be varied incrementally to satisfy user preferences for heat and sunlight. The opacity of the glass can be controlled by a simple on-off switch, a user-adjustable rheostat to meet individual user preferences of heat and sunlight, or an automatic system driven by sensors or timing devices.

Unequal Company Progress

Previous to the ATP-funded research, the state-of-the-art capability in producing electrochromic materials for windows resulted in a laboratory curiosity, a piece of glass measuring less than two square inches. Furthermore, the EC properties of the tiny piece of glass were not well understood.

During the project, SAGE moved forward successfully with its materials and process research on EC glass, and met with great success. 3M, on the other hand, encountered obstacles in managing the heat level in the production of its tapes. A method of controlling the heat level was needed to avoid melting the tapes. This serious obstacle that the company was not able to solve caused it to reduce its role to a supporting one for SAGE.

SAGE Prototype Smart Windows Best Rivals in Critical Performance Tests

By the end of the project, SAGE was able to produce prototype smart windows approximately one square foot in size that incorporated the new technology and demonstrated the performance characteristics and decade-long durability of EC glass required by the architectural glass industry. This new capability represented a major step forward, both technically and in terms of demonstrating commercial potential for the technology.

The functional EC window prototypes produced in the ATP research project were subjected to independent performance tests in an outdoor desert environment and at the National Renewable Energy Laboratory (NREL). NREL, the world's leading certification laboratory for energy saving technology, used a solar simulator with xenon lamps to test alternative smart window designs for environmental longevity. Competing technological approaches from other companies each had their relative strengths, but the SAGE smart windows displayed the best overall performance.

The rigorous tests demonstrated that the new SAGE windows are capable of tens of thousands of tint changes (cycling) without degrading. This translates into more than 15 simulated years of harsh sun while maintaining adequate performance. ¹ Architectural consumers currently expect warranties of at least 15 years and useful lives of at least 20 to 25 years. These tests show that electrochromic windows, especially SAGE's design, hold great promise in meeting the longevity required for commercial building use.

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At the end of the project, the company was ready to take the next step: scaling up to full size electrochromic windows for architectural applications on residential and commercial buildings. SAGE moved toward this goal, keeping in mind for commercialization purposes that it was critical the EC windows could be manufactured in volume at reduced cost.

Commercialization Agreement with Largest Specialty Glassmaker in North America

SAGE announced on June 17, 1998 — about a year and a half after the project completed — that it had reached an agreement with Apogee Enterprises, Inc., to develop, produce, and market smart windows. ² The company promptly relocated from New Jersey into a corner of Apogee's Viratec manufacturing plant in Minnesota. This commercialization venture is a direct result of the encouraging test results for the prototype windows. Apogee, a large fabricator, distributor, and installer of high-end, specialty glass products in North America, and its subsidiary Viracon, will commercialize the licensed smart windows for mass distribution in the high performance architectural glass market.

Viracon has extensive experience in producing glass

¹ SRI Report, Smart Glass: Seeking a Clear View of the Future, 1998, p. 15.

² PRN Newswire, June 16, 1998 Press Release.

products with high performance coatings, and supplies a large global window market. These two strengths will help the new SAGE-Viracon team take the electrochromic technology more quickly to full-scale production. There is, however, a difficulty that will have to be addressed before cost-competitive architectural windows can be produced: the control of defects in

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large size films. Since current prototypes had not been produced in a size greater than one square foot, it was critical that Viracon be able to develop a manufacturing capability for producing larger EC windows. SAGE has received a Department of Energy/ National Energy Technology Lab grant from the Department of Energy to improve the manufacture of smart windows on a large scale.

ATP Brings Together Complementary Companies

The ATP project manager, Dr. Gerald Ceasar, with his extensive industry experience with electrochromics and photovoltaics technology, saw potential commonality of interests of Solarex, a photovoltaic company, and SAGE. He made the introductions and this technology brokering soon yielded the integration of photovoltaics into the new smart window design. The inclusion of photovoltaics (in the form of built-in sensors) will allow engineers to set the windows to adjust automatically to changing sunlight conditions. Photovoltaics (in the form of energy producing solar collectors) can also provide all of the energy needed to power the window, thus eliminating the need for external wiring.

In the future, integrated photovoltaics may even be able to produce excess electricity that could power all or part of the entire building and pay for the new windows many times over. Ultimately, this may reduce the life-cycle costs of purchasing, installing and operating windowed buildings. Technology integration, encouraged by ATP managers, means connecting emerging technologies from different companies and industry sectors together in mutually beneficial ways.

SAGE Moves Ahead of International Rivals in Smart Window Technology

Although SAGE had been awarded a total of 7 patents for its electrochromic technology before the ATP project, approximately 1,800 patents had been issued worldwide for electrochromic technology. Of those patents, Japanese interests hold 1,500.³ The Japanese, Europeans, and Australians have all mounted major efforts to develop EC technology.⁴ In Australia, for example, researchers at Monash University are developing an energy-efficient smart window, an effort that has been underway for the past five years as part of a \$3 million project. The Australian Science and Technology Administration targeted the new windows to be ready for large-scale commercial production around the turn of the century.⁵

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The competition for leadership in EC windows around the world is intense. As a result of the ATP award, SAGE was able to speed the research in collaboration with 3M, and get an advanced prototype to product test more quickly than overseas competitors. According to SAGE project manager Neil S. Sbar,

Early support from ATP was critical in enabling SAGE to develop the electrochromic (EC) materials systems and device structure for scaling the technology from a laboratory curiosity to switchable prototype windows nearly one square foot in size. Without ATP, our progress would have been delayed by more than two years. Also, the prestige and credibility derived from the relationship greatly facilitated subsequent industry and government partnerships leading to full size EC window fabrication.⁶ And, according to SAGE president John Van Dine, [ATP] enabled us to accelerate and expand our technology development and put our company into a better internationally competitive position.⁷

Smart Windows Beat Traditional Glazed Windows for Energy Efficiency

The price-sensitive architectural market will require

3 Jeffery Kahn, "Researchers Seek Patents on Electrochromic Smart Windows," February 14, 1992, Berkeley Lab Science Articles Archive.

4 Michael Rubin, Lawrence Berkeley National Laboratory, personal interview, August 5, 1998.

5 Monash Publications, University Marketing & Development, Monash University, Australia; <www.monash.edu.au/pubs/eureka/Eureka_95/window.html> web page accessed July 8, 1998.

6 Telephone interview and personal correspondence with Dr. Neil S. Sbar, December 2000.

7 NIST website: <www.atp.nist.gov/atp/success/sage.htm>.

significant cost savings over the life of the window to justify a major market shift away from single-glazed and multi-glazed windows. Based on test results, full-size replacement smart windows can reduce peak loads for lighting, heating, and cooling up to 60 percent when compared to high-end glazed windows. And they can reduce peak loads up to 85 percent compared to single-glazed clear glass, ⁸ which blocks only 21 percent of solar heat gain into the room. ⁹ To accomplish these results, electrochromic smart windows reduce the transmittance of light and heat, depending on the setting, by 30 to 96 percent.

...Smart windows could pay for themselves in as little as four years.

Even at this early stage of electrochromic window development, savings of \$0.21 per square foot in areas of the country that have cooling-intensive building loads have been calculated, based on \$0.08/kWh electricity costs. Thus, a medium-sized office building (100,000 square feet), with windows covering 60 percent of the outside surface, could see operating savings on the order of \$21,000 per year if smart windows are used. ¹⁰ Over a 25-year life, these savings would have a present value of \$365,000 (based on a 3 percent real [net of inflation] discount rate, and assuming stable energy costs [also net of inflation] ¹¹).

Cost analysis that includes direct energy costs, initial chiller investments, utility demand-side management rebates, and lighting savings indicate that smart windows (at an added first cost of \$161/m²) could pay for themselves in as little as four years. ¹²

A recent American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) study showed that EC windows could provide energy efficiency performance comparable to a well-insulated wall. For a building located in a cooling-dominated environment (e.g., Phoenix, Miami, Los Angeles), the study estimates that smart windows will significantly lower heat gain and the energy demands of cooling. The ASHRAE work also found that lighting expenditures could be significantly reduced because smart windows, when bleached, allow more light to enter the room than standard windows. In heating-dominated areas (e.g., Chicago, or Greenbay), smart windows can increase the solar heat gain

compared to standard windows, reducing heating costs in winter and cooling costs in summer. The study found that the cooling savings of windows with reflective glazing are comparable to those with electrochromics. The total energy savings, including that from reduced lighting demands, however, favor smart windows technology, in spite of its higher initial costs. ¹³ Twenty billion dollars is the estimated value of the energy lost through the windows of buildings in the United States each year. This represents more than five percent of total U.S. annual energy use. ¹⁴ Globally, a phased-in total transition to smart window systems in office buildings could translate into energy savings on the order of \$11.5 billion to \$22.5 billion per year. ¹⁵

Although this full potential is unlikely to be realized any time soon, smart windows promise eventually to have a significant impact on world window and energy markets as they enter commercial production and are adopted by architects, builders, and building owners as a means of achieving dynamic control of heat and light gain into a building

An architectural advantage of electrochromic windows is that they eliminate glare and the need for other shading devices. Automated or manual blinds, curtains, and shutters can be expensive to install, maintain, and clean. Reducing costs in this area will enhance the commercial viability of smart windows. Light has also been shown to be an important factor for the work environment. Studies demonstrate that allowing sunlight to fill offices (otherwise shaded by permanent glazes) can increase productivity, lead to fewer days of absenteeism, and fewer errors on the job. ¹⁶

Smart Window Technology Is Potentially Far Reaching

Enabling advances in electrochromic technology resulting from this ATP funded project have encouraged the application of large-area electronics to other commercial products, beyond the scope of window applications. Researchers are currently working to apply the ion shuffling capabilities of electrochromics to thin film flat batteries for use in consumer electronics, such as cellular phones and laptop computers, which may then be able to operate significantly longer and with much lower weight. Auto-mobile windows and adjustable eyewear are examples of where the advances of electrochromics may have future market potential. The future is bright for the broad use of large-area electronics, and the foundations are being laid today.

8 Facilities Design and Management, April 1996, p. 15.

9 SRI Report, Smart Glass: Seeking a Clear View of the Future, 1998, p. 12.

10 Rubin, Selkowitz, Sullivan, ASHRAE Transactions, June 1997, pp.149-153.

11 U.S. Dept. of Energy, Annual Energy Outlook 1998, Energy Information Administration, 1998, p. 80.

12 Lee, Rubin, Selkowitz, Sullivan, Review of Electrochromic Window Performance Factors, Lawrence Berkeley Laboratory Report # 35486, p. 14, 1994.

13 Rubin, Selkowitz, Sullivan, ASHRAE Transactions, June 1997, pp.149-153.

14 SRI Report, Smart Glass: Seeking a Clear View of the Future, 1998, p. 2.

15 Ibid.

16 LaSourd, Selkowitz, Lawrence Berkley Laboratory, June 1994, p. 111.